1. **Project Name:** **Development of a New Class of Fe-3Cr-W(V) Ferritic Steels for Industrial Process Applications**

2. **Lead Organization:** Nooter Corporation
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   St. Louis, MO 63104

3. **Principal Investigator:** Dr. Maan H. Jawad
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4. **Project Partners:**

   Nooter Corporation, **DOE and In-kind**: Develop fabrication and welding process data and coordinate overall project; Contacts: Maan Jawad (314) 846-8808, Fax (314) 846-3777, maanjawad@aol.com; Mark Huck 421-7309, Fax (314) 421-7395, mfhuck@nooter.com
   ExxonMobil Chemical Company, Contact: Jeff Jones, **In-kind**: Identify applications and test coupons and prototype components
   BP Amoco, Contact: Don Chronister, **In-kind**: High-temperature hydrogen attack and sulfidation and assist in component testing
   DuPont, Contact: Bert Moniz, **In-kind**: Coupon and prototype component testing
   ISG Plate, Contact: Kenneth Orie, **In-kind**: Production of large heats, production of hot-rolled plate, and forgings
   Ellwood Materials Technologies, Contact: John Paules, **In-kind**: Melting of large heats and production of forged components
   Ellwood National Forge Company, Contact: Fred Venal, **In-kind**: Melting and production of large forgings
   Plymouth Tube Company, Contact: Bob Curry, **In-kind**: Fabrication of tubes and their qualification
   Stoody Company, Contact: Ravi Menon, **In-kind**: Production of flux-cored wire and welding qualification
   Nooter Eriksen, Contact: Joe Schroeder, **In-kind**: Evaluate commercial applications in heat recovery, power generation, and petrochemical industries
   Oak Ridge National Laboratory, Contact: Vinod K. Sikka, **DOE**: Project coordination, thermodynamic and kinetic modeling, alloy design and heat treatment, microstructural analysis, melting and processing of commercial-size heats, mechanical properties, preparation of ASTM and ASME Code data packages

5. **Date Project Initiated:** 09/30/2001 **FY of Effort:** FY 2003

6. **Expected Completion Date:** 09/29/2004

7. **Project Technical Milestones and Schedule:**

   Objective: The objective of the project is to develop a new class of Fe-3Cr-W(V) steels with (a) 50% higher tensile strength up to 650˚C than current alloys, (b) potential for not requiring any postweld heat treatment (PWHT), (c) reducing the equipment weight by 25%, and (d) with impact properties of approximately 100 ft-lb of upper shelf energy and -10˚F (-20˚C) for ductile-to-brittle transition temperature (DBTT) **without tempering treatment**.

Goal: The project goal is to reduce the weight of large pressure vessel and associated components by approximately 25% and eliminate the need for PWHTs with estimated energy savings of 21 trillion BTU/year and cost savings of approximately $237 million for chemical vessel and related components used in the United States.

1. Alloying Effects and Composition Optimization (9/30/02)
   1.1 ThermoCalc™ and kinetic modeling to understand effects of tungsten versus molybdenum (3/31/02)
   1.2 Development of TTT curves for heat treatment (6/30/02)
   1.3 Verification of compositions and heat treatment (9/30/02)
2. Materials/Process Modeling (9/29/04)
   2.1 Methods for melting pilot heats (11/31/02)
   2.2 Modeling and processing of heats into rolled plate, forged sections, and casting (8/31/03)
   2.3 Mechanical properties of pilot and large heats (9/30/04)
3. Welding Process Development (9/29/04)
   3.1 Process and filler metal development (9/30/03)
   3.2 Weld and weldment properties (9/30/04)
4. Microstructural Thermal Stability and Characterization (9/29/04)
   4.1 Thermal aging of pilot and large heats to various temperatures and times (9/30/03)
   4.2 Properties of aged materials (9/30/04)
   4.3 Microstructural characterization (9/30/04)
5. Manufacturing and Testing of Prototype Components (4/30/04)
   5.1 Fabrication of welded and cast components (10/31/03)
   5.2 Installation of components in chemical plant (11/30/03)
   5.3 Cost benefit analysis (4/30/04)
6. Preparation of Data Packages for ASTM and ASME Code (9/29/04)
   6.1 Complete data package for ASTM Specification (9/30/03)
   6.2 Complete data package for ASME Code approval (9/30/04)
7. Meetings and Reports (9/29/04)
   7.1 Hold at least two technical meetings per year (9/30/04)
   7.2 Complete final report (9/30/04)

8. **Past Project Milestones and Accomplishments:**

1. Alloying Effects and Composition Optimization: (Milestones 1.1, 1.2, and 1.3 – completed on schedule). These milestones dealt with alloy composition optimization through the use of ThermoCalc™ modeling, melting and processing of experimental size heats, testing of the alloys for Charpy, tensile, and creep, microstructural analysis, effects of heat treatment (normalized, normalized and tempered, quenched, and quenched and tempered), and development of a time-temperature-transformation diagram. All aspects of the milestone were met. The composition ranges developed during this milestone were filed as a patent application.

2. Materials/Process Modeling: (Milestones 2.1 completed on schedule and 2.2 is on target). These milestones dealt with methods for melting the pilot scale heats (air versus vacuum induction). The temperatures for forging and rolling were identified. Each heat was produced into approximately 0.5-in.-thick plate for heat treating and mechanical property testing. Each heat was analyzed in detail for recovery of various elements and pick-up of impurity elements.
3. Welding Process Development: (Milestone 3.1 – may be delayed somewhat). A major effort during the past calendar year was devoted to this milestone. The milestone required the development of filler wire composition for gas tungsten arc (GTA) and submerged arc (SA) processes that will yield good impact properties without requiring postweld heat treatment (PWHT). The major outcome from this milestone is the identification of the filler wire for GTA process that yields excellent impact properties without PWHT. For the SA process, obtaining the good Charpy properties required optimization of additional parameters such as flux, preheat and interpass temperature, and heat input. Significant progress has been made in all aspects of this welding process. However, the final filler wire composition still requires some additional optimization, which is currently underway.
4. Meetings and Reports: A major review meeting with all partners was held on July 23-24, 2002. In addition, several meetings have been held at ORNL between Nooter Corporation and ORNL. Meetings have also been held at Nooter Corporation with ORNL and Stoody Company, and the last meeting was held at Stoody Company on April 21-22, 2003 with Nooter Corporation and ORNL. All quarterly and annual reports were submitted on schedule.

9. **Planned Future Milestones:**

Plans for the future milestones during the next calendar year are given below as related to each milestone.

2. Materials/Process Modeling (Milestone 2.2): This milestone is delayed by six months while waiting on optimizing SA properties. Major activity planned for this milestone is to review all of the mechanical properties data on experimental heats and their welding response and finalize composition for melting of large size (~ 5 to 40 ton) heats at a commercial vendor. The finalizing of composition for large heats is expected by the end of June 2003. The commercially melted heats will also be processed by forging, rolling, and other operations into various product forms, which will be characterized for their mechanical properties and welding.
3. Welding Process Development (Milestone 3.1): In this milestone, a filler wire composition for SA welds of acceptable impact properties will be finalized along with the weld procedure including the choice of flux, preheat, interpass temperature, and any PWHT. Several welds will be made for conducting tensile and creep testing of weldments.
4. Microstructural Thermal Stability and Characterization (Milestone 4.1): Pilot heats of the chosen composition will be processed into 0.5-in.-thick plate. The sections of the plate will be exposed to thermal aging treatment at 900, 1000, 1100, and 1200°F. This will begin by the middle of July 2003.

5. Manufacturing and Testing of Prototype Components (Milestone 5.1): As large heats will be melted, prototype components such as tubing will be produced. We will work with the project partners to get some of the tubes and other components installed in the production plants.
6. Preparation of Data Packages for ASTM and ASME Code Approvals (Milestone 6.1): As large heats are melted and characterized, their data along with the data on the experimental heats will be used to prepare the ASTM package for approval of composition specification. The ASME Code package preparations will also begin.
7. Meetings and Reports: A review meeting with all partners will be planned for July-August 2003. Meetings between Nooter Corporation, ORNL, and other partners will continue as needed. Reports will be submitted as needed.

10. **Issues/Barriers:**

The major issue was not being able to obtain the desired properties in the SA welds without a PWHT within the anticipated time period. The SA welding is a significantly complex process than the GTA welding because it requires optimization of not only the filler but also the flux. A systematic study is being conducted to optimize the flux and filler wire. The flux has already been optimized and additional R&D is planned for development of the filler wire. Additional effort with regard to optimizing the SA welding process will delay the procurement of commercial size heats for ASME Code development.

11. **Intended Market and Commercialization Plans/Progress:**

The ferritic steels of this project has applications for hydrocrackers and hydrotreaters for the chemical and petrochemical industry and industrial heat recovery systems for many of the IOF industries including chemical, petrochemical, pulp and paper, steel, glass, aluminum, etc. Product forms to be used will include plate, tubing, piping, forgings, and castings. The ultimate market potential for this steel will be in **millions of tons per year**. The product of this research will be material property data and design allowable stress values approved by ASME Code. The product forms of this research will be installed for in-service operating experience at various application sites for the relevant IOFs. Nooter Corporation will commercialize the material through the current partners.

12. **Patents, publications, presentations:** (Please list number and reference, if applicable.)

A new invention disclosure (ID 1156, S-99,347) entitled "Improved Cr-W-V Bainitic/Ferritic Steel Composition" was filed on September 19, 2002 (for U.S. and international coverage).

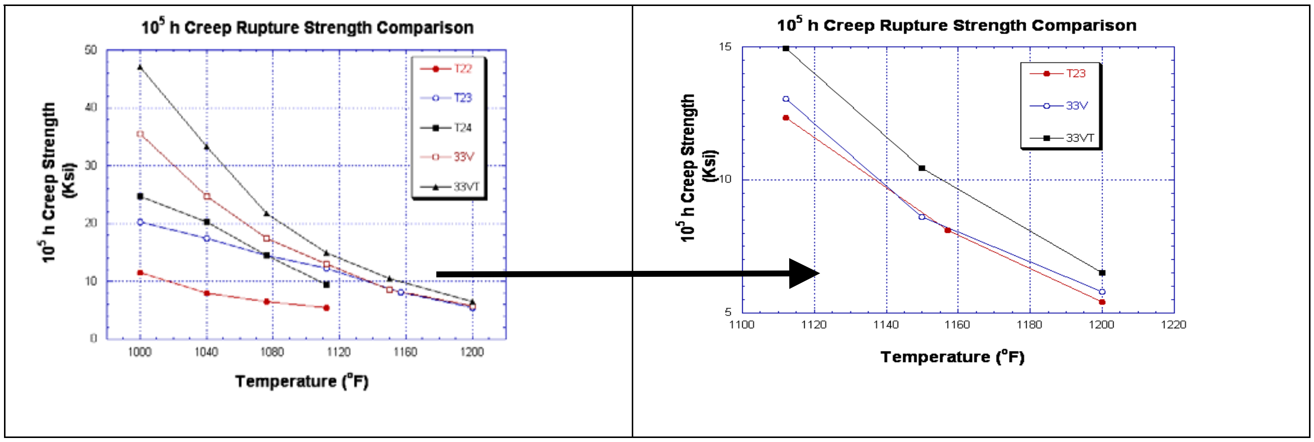
Highlight: ID-08

Project: Development of a new class of Fe-3Cr-W(V) ferritic steels for industrial process applications.

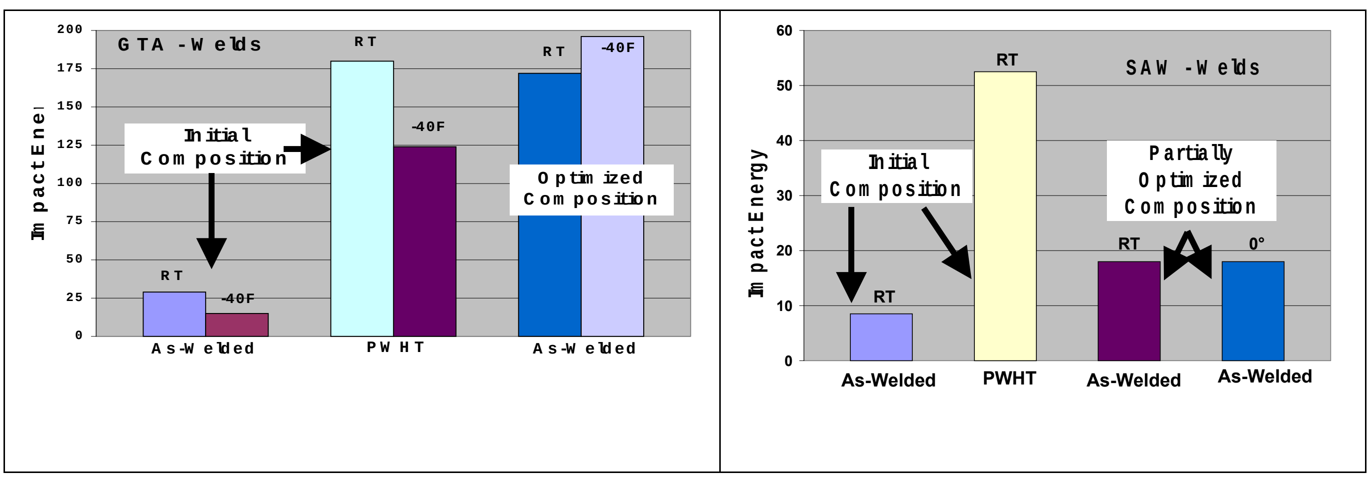
Objective: This project is focusing on developing and commercializing Fe-3Cr-W(V) ferritic steels with higher creep strength than currently used alloys, excellent impact properties and with the possibility of using welds without requiring a Post Weld Heat Treatment (PWHT).

Results: A combination of Thermocalc™ modeling, experimental testing and welding method development has produced significant results addressing the objective.

- Creep rupture properties of the new compositions (33V & 33VT) are the highest in its class of steels T22, T23 and T24 (2 ¼ - 3% Cr). See the figure below.



- Elimination of PWHT has been demonstrated for GTA Welds. As-welded impact values match values with PWHT. See the figure below.



- Alloy composition developed in this project has been submitted for US and international patent application.

Significance to IOF: New steels have applications in many of the IOFs with benefits of reduced section thickness of components with energy and cost benefits from ease of forming and welding operations of thin sections.